THE MODIFIABILITY OF TRANSPIRATION IN YOUNG SEEDLINGS

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(WITH FIVE FIGURES)

The writer has often noticed the fact that young seedlings (e. g., of Cucurbita and Phaseolus) grown under bell glasses wilted almost at once when exposed to the dry air of a furnace-heated or steam-heated room. Gardeners all know that plants started in cold frames must be "hardened" by gradual exposure to the ordinary atmosphere, brought about by lifting slightly the sashes with which the cold frames are covered.

It appeared worth while to investigate quantitatively the rate of transpiration of these tender seedlings, grown in an extremely moist atmosphere, and the simplest possible case for study seemed to be that of annuals, for these cannot be supposed to have inherited a tendency to develop extreme adaptations to an abnormally moist atmosphere during part of the brief lifetime of the individual plant. Seedlings of the following species were grown in well-watered earth, some under glass cases with air-tight joints, and others in the free air of a furnace-heated room.

Cucumis sativus
Ipomoea purpurea
Lupinus albus
Mirabilis Jalapa
Nicotiana "Sanderae"
Oxalis corniculata
Phaseolus vulgaris
Salvia splendens
Sinapis alba

The temperature was on the average about the same for the covered and the uncovered plants; the former, of course, received a trifle less light than the latter. The moisture of the atmosphere about the leaves naturally differed greatly. Those in glass cases were in a nearly or often quite saturated atmosphere. Those in the free air of the room were in an atmosphere of which the relative humidity during the winter months ranged from 16 to 32 per cent., averaging less than 25 per cent. This is drier than the average summer atmosphere of an oasis in the Sahara. Some plants were also grown in a

greenhouse, where the relative humidity was usually not far from 60 per cent.[1]

In general the plants grown in nearly saturated air and in dry air or in that of moderate humidity presented considerable contrasts in their development.[2] Those from moist air were taller, more slender, longer-leaved, less hairy (if the plant were naturally pubescent), with

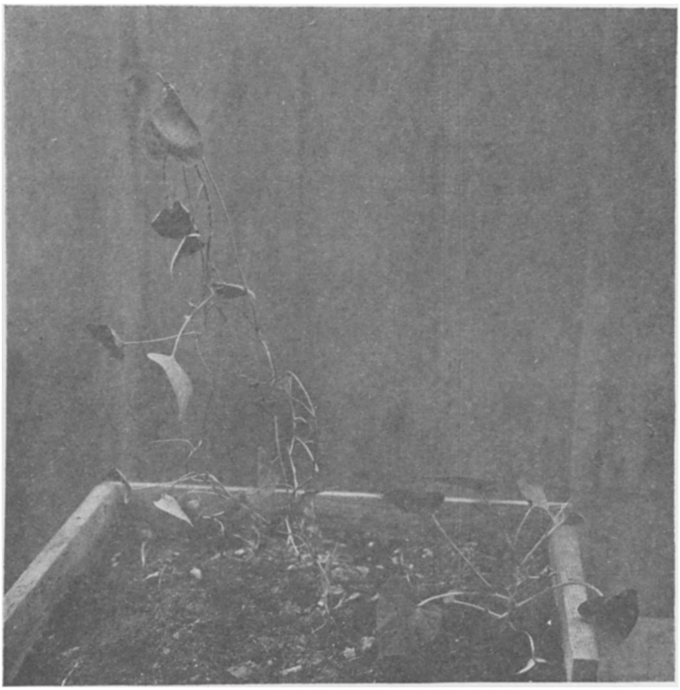

FIG. 1.—Ipomoea plants, moist-air form and dry-air form. ×¾. Photographed by ROBERT CAMERON.

thinner, lighter-colored, more pliable, and more translucent leaves. In many cases the moist-air plants showed an accelerated development, producing more leaves in a given time and flowering earlier than those in drier air. Most of the exact measurements of relative

[1] The writer's thanks are due to Professor GEORGE L. GOODALE of Harvard University for the use of space in the greenhouses of the university.

[2] See WIESNER, J., Formänderungen von Pflanzen bei Cultur im absolut feuchten Raume und im Dunkeln. Ber. Deutsch. Bot. Gesells. 9:46–531. 1891.

development were made on plants of Phaseolus. In different lots of these, the moist-air individuals were 15 to 40 per cent. taller than those grown in drier air. The leaves of the former were sometimes as much as 80 per cent. longer than those of the latter, the difference being largely in the petioles. On the other hand, the diameter of the first internode above the cotyledons was (in plants grown in the greenhouse) 30 per cent. greater for those outside the moist glass cases. For house-grown plants the leaf thickness was 25 to 40 per cent. greater in the dry-air plants, and for those grown in the greenhouse

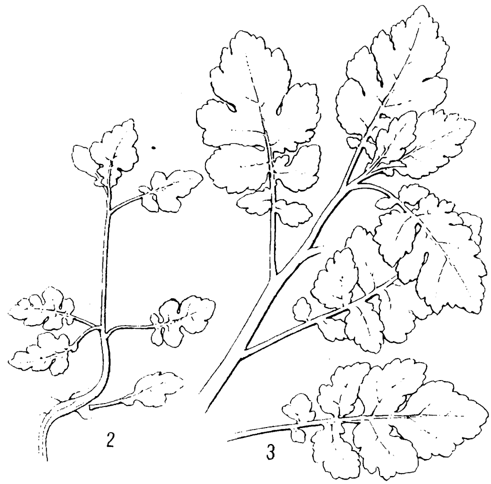

FIG. 2. Sinapis, entire stem and leaves, moist-air form. $\times\frac{1}{3}$.—FIG. 3. Sinapis, upper half of stem and leaves, dry-air form. $\times\frac{1}{3}$.

it was 25 per cent. greater than for those under glass cases. The most notable differences in growth of dry-air and moist-air individuals were shown by Ipomoea, in which the moist-air specimens were twining freely, when dry-air specimens of the same age had relatively short internodes and showed no tendency to twine (*fig. 1*). Mirabilis plants in nearly saturated air, by the time the second pair of true leaves had spread apart, were three times as tall as those grown in house air and much more slender. Sinapis, on the other hand, appears depauperate when grown in nearly saturated air, as shown in *figs. 2, 3*. The leaves of Sinapis, and of Cucumis also, in very moist air often show the less indented margin referred to by WIESNER.[3]

3 WIESNER, J., Biologie der Pflanzen 65, 66. Wien. 1902.

The relative translucency of moist-air leaves and dry-air leaves was approximately measured in the case of Nicotiana and of Ipomoea by blue-printing them with various terms of exposure to sunlight, until an equal degree of blueness was obtained for the portions of paper covered by each kind of leaves.[4] The moist-air leaves of Ipomoea were found to be 3.5 times as translucent as the others, and those of Nicotiana 3 times. In the latter plant many of the first leaves grown in moist air stand nearly vertical, while those of the dry-air plants form approximate rosettes. This vertical growth of the moist-air leaves is exactly the reverse of the epinasty of the leaves of *Sempervivum tectorum* and *Oxalis floribunda* noted by WIESNER.[2] The differences in form and size between Nicotiana leaves and Ipomoea leaves grown under moist and under dry conditions are shown in *figs. 4, 5.*

The histology of the leaves studied did not differ nearly as much as it often does in sun plants and shade plants of the same species. In house-grown individuals of Phaseolus, leaves developed in dry air exceeded in thickness those in the glass cases by 25 to 33 per cent., the upper epidermis of the former was about 25 per cent. thicker, and the palisade layer was a little thicker. On the other hand, moist-air leaves of Sinapis were found to be a little thicker, and of Ipomoea sometimes 25 per cent. thicker, than leaves of these genera grown in dry air. As might have been expected, less notable differences were found between leaves grown in air nearly saturated with moisture and those grown in the moderately moist air of the greenhouse.

The behavior of moist-air leaves and dry-air leaves, on being deprived of a water supply and exposed to air at a temperature of about 21° C. and 25 per cent. relative humidity, differs greatly. If a shoot of each kind is cut and exposed to such air, in many cases (Brassica, Cucumis, Ipomoea, Oxalis, Phaseolus) wilting begins in from 0.5 to 2 minutes. Even if the shoots are cut under water and kept with the cut end always submerged, wilting is prompt and continuous. Shoots of Phaseolus were cut and laid in sunshine, in air of humidity probably below 25 per cent., at a temperature of 23°.3 C. One shoot was from the saturated air of the glass case, the other from

[4] This of course only measures translucency with reference to those rays which affect the blue-print paper

dry house air. Bits of the lower epidermis were peeled from the under surface of each kind of leaf at about 2-minute intervals and instantly placed in absolute alcohol to fix the stomata.[5] The operation was repeated on another day with fresh sets of leaves. It was found that in less than six minutes the stomata of the dry-air leaves were most of them closed to less than half their initial width, while

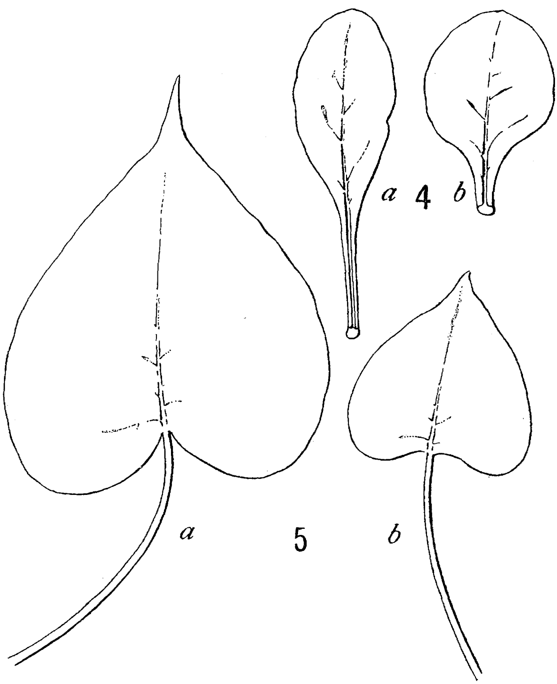

FIG. 4. Nicotiana leaves; *A*, moist-air form; *B*, dry-air form. $\times\frac{1}{2}$.—FIG. 5. Ipomoea leaves; *A*, moist-air form; *B*, dry-air form. $\times\frac{1}{2}$.

those of the moist-air leaves were but little affected. In about 15 minutes most of the stomata of the dry-air leaves were tightly closed, while most of those of the moist-air leaves still remained open. Apparently the speedy wilting of the moist-air leaves is due to two causes, the insufficient closure of the stomata and the relatively high permeability of the general surface of the epidermis to moisture.

5 LLOYD, F. E., The physiology of stomata. Publ. 82, Carnegie Institution of Washington. 1908.

A curious kind of quick adaptation to dry conditions may sometimes be noted. Young leaves of Ipomoea, grown in nearly saturated air, were found to wilt in air of less than 30 per cent. relative humidity in about two minutes, though the stem was cut off under water and kept immersed in water. After being left for some hours in a saturated atmosphere until the wilting had entirely disappeared, the shoots were left, with the cut ends in water, in an atmosphere of less than 30 per cent. relative humidity for 48 hours without showing any signs of wilting. More than 90 per cent. of the stomata were at this time found to be perfectly closed.

The relative transpiration rate in diffuse light of moist-air and dry-air leaves of nearly all the kinds of seedlings grown was carefully determined. Attempts to make use of very slender (and therefore quick-reading) burettes as potometers were not successful. It was found too difficult to attach the soft and readily crushed stems of young seedlings to the burettes in such a way as to be sure to obviate leakage. All losses by transpiration were therefore estimated by weighing the shoots and the tubes of water which contained them on a balance sensitive to 5^{mg}. The relative humidity of the air in which the transpiration took place was measured by the sling psychrometer (sometimes twice) during each experiment. As might have been expected, the inequality of transpiration was found to be greatest in the case of fully developed leaves, half-grown ones showing less, though notable, differences. The values given below are for the ratio M/D, in which M is the transpiration of the moist-air leaf and D the transpiration of the dry-air leaf.

In discussing the results above given, it should be noted that a considerable range of values in the ratios obtained is almost unavoidable. In the first place we have to reckon with the great variability of transpiration in individuals of the same species grown under identical conditions. F. HABERLANDT[6] found in the case of rye plants that the transpiration per day varied (in round numbers) from 2 to 7^{gm} per square decimeter for different individuals. Also, if the transpiration were allowed to take place in a nearly saturated atmosphere (to prevent sudden wilting), the leaves would be under condi-

[6] HABERLANDT, F., Wissensch.-prakt. Untersuchungen auf dem Gebiete des Pflanzenbaues 2:146. Wien. 1877.

tions abnormal for the kinds of plants studied. If the atmosphere were to be made very dry, the leaves grown in very damp air would wilt inside of five minutes or less and die in a comparatively short time. In some cases it was found best to determine the transpiration of readily wilted leaves for a period of fifteen minutes and compare

TRANSPIRATION RATIOS

Kind of leaf	Rel. humid. during trans. period	Ratio M/D
Phaseolus..........	25	2.2
Phaseolus..........	63	2.5
Phaseolus..........	64	3.2
Lupinus...........	26	4.0
Lupinus...........	about 43	8.2
Lupinus...........	about 38	10.0
Lupinus...........	variable, probably over 40	1.9*
Mirabilis...........	36	3.9
Mirabilis...........	29	4.8
Ipomoea...........	26	7.4
Salvia.............	34	6.6
Salvia.............	..†	8.9
Sinapis............	28	3.5
Cucumis...........	24	3.9*
Cucumis...........	34	9.3
Nicotiana..........	about 50	3.1

* Young leaves, only half grown or less.

† The moist-air leaves transpired on May 12 in air of 28 per cent. relative humidity, and the dry-air ones on May 13 in air of 34 per cent. relative humidity.

this with the (calculated) fifteen-minute loss of the dry-air leaf of the same species, allowed to transpire for one or two hours. *Oxalis corniculata* from saturated air became wholly wilted inside of one minute, on being removed from the glass case, so its transpiration ratio could not be determined. It would be interesting to compare the relative transpiration of the two kinds of leaves in extremely dry air minute by minute, but weighings on a balance delicate enough for this purpose could not be made with sufficient rapidity.

The conditions as regards relative humidity were intentionally varied a good deal, in order to show whether the transpiration ratios follow closely the changes in humidity. It is evident that in Phaseolus and Lupinus they do not.

While no experiments were made with a view of measuring the absolute rates of transpiration of the plants studied, all under the same conditions of temperature and humidity, it may be worth

while to give the values obtained for moist-air leaves of some of them.

TRANSPIRATION OF 100 SQ. CM. OF LEAF IN AN HOUR

Plant	Temperature °C	Rel. humid. per cent.	Transpiration in milligrams
Cucumis......	20	34	1485
Lupinus.......	21.67	43	3596
Nicotiana.....	21.11	50 or less	1950
Phaseolus.....	26.11	25	1647
Sinapis........	22.22	28	2135

Summarizing the results obtained from the transpiration measurements,[7] it may be said that:

1. As a result of being grown in a highly humid atmosphere, all the plants studied acquire a much greater than normal capacity for transpiration in a moderately dry atmosphere.

2. Different families and different genera of the same family vary greatly in their capacity to acquire by such culture a tendency to extremely rapid transpiration.

3. The transpiration ratios, for the same species, become notably greater as the leaf becomes fully developed.

4. The transpiration ratios are not necessarily greater when the relative humidity of the air, during the period when transpiration is measured, is very low than when it has a medium value.

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[7] Not nearly all of these results have been tabulated in the preceding pages.